

Mesoscale and meso-urban meteorological and photochemical modeling of heat island mitigation in California

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Acknowledgements

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Sacramento Metropolitan AQMD – UFFCA Project

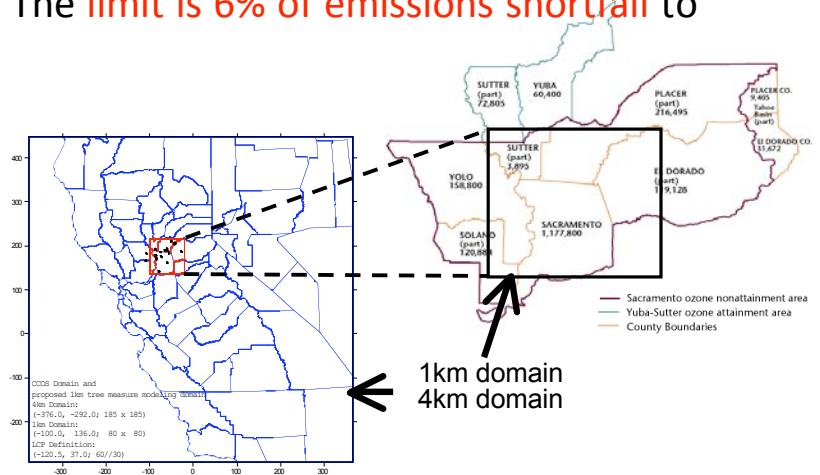
Why consider UHI control in *air quality* regulations

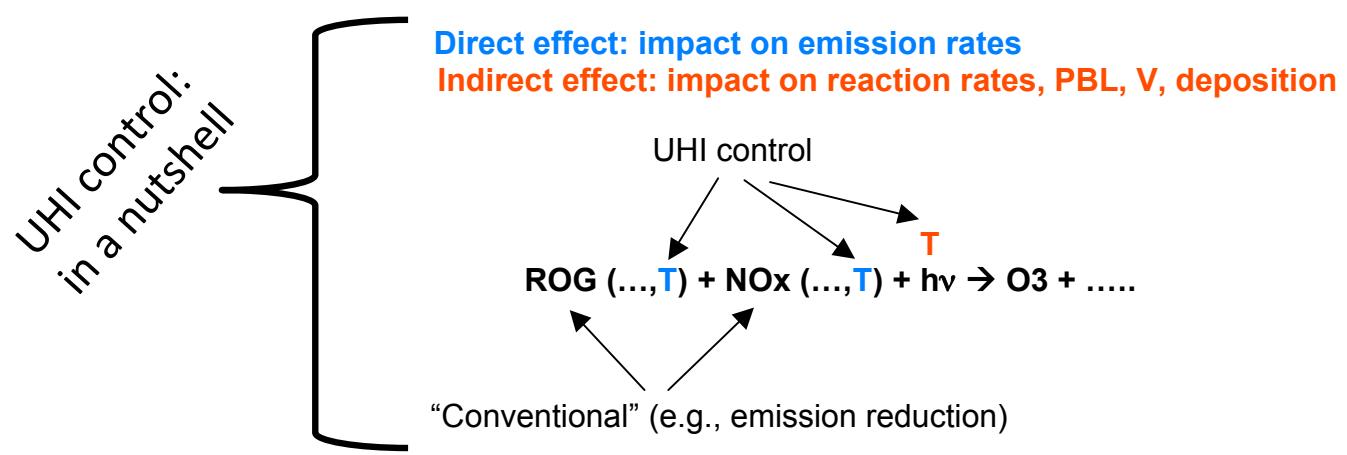
- Urbanization and land-use / land-cover changes, and associated changes in emissions and meteorology, have the potential to impact **a region's attainment status** – in the short term and under future climates
- UHI control can help **maintain / improve air quality**: national interest in incorporation of UHI mitigation into regulatory frameworks (direct / indirect, energy / atmospheric pathways)
- Cool roofs – California **Title 24**
- ARB: climate change early action: high-albedo materials (buildings, automotive cool paints' portion of the **AB32 Early Action Plan**)

Incorporating UHI mitigation in SIP (so far)

- Per EPA / OAQPS: A **voluntary** measure is a measure or strategy that is not enforceable against an individual source. An **emerging** measure is a measure or strategy that does not have the same high level of certainty as traditional measures for quantification purposes.
- An emerging and/or voluntary measure (such as UHI control), requires state-of-science **technological assessment**. In addition to **direct measurements**, **coupled meteorological-emissions-photochemical modeling** is one of the best options available to demonstrate effectiveness of control strategy.
- EPA believes it is appropriate to limit these measures to a small portion of the SIP given the untested nature of the control mechanisms. The **limit is 6% of emissions shortfall** to reach attainment or for maintenance purposes.

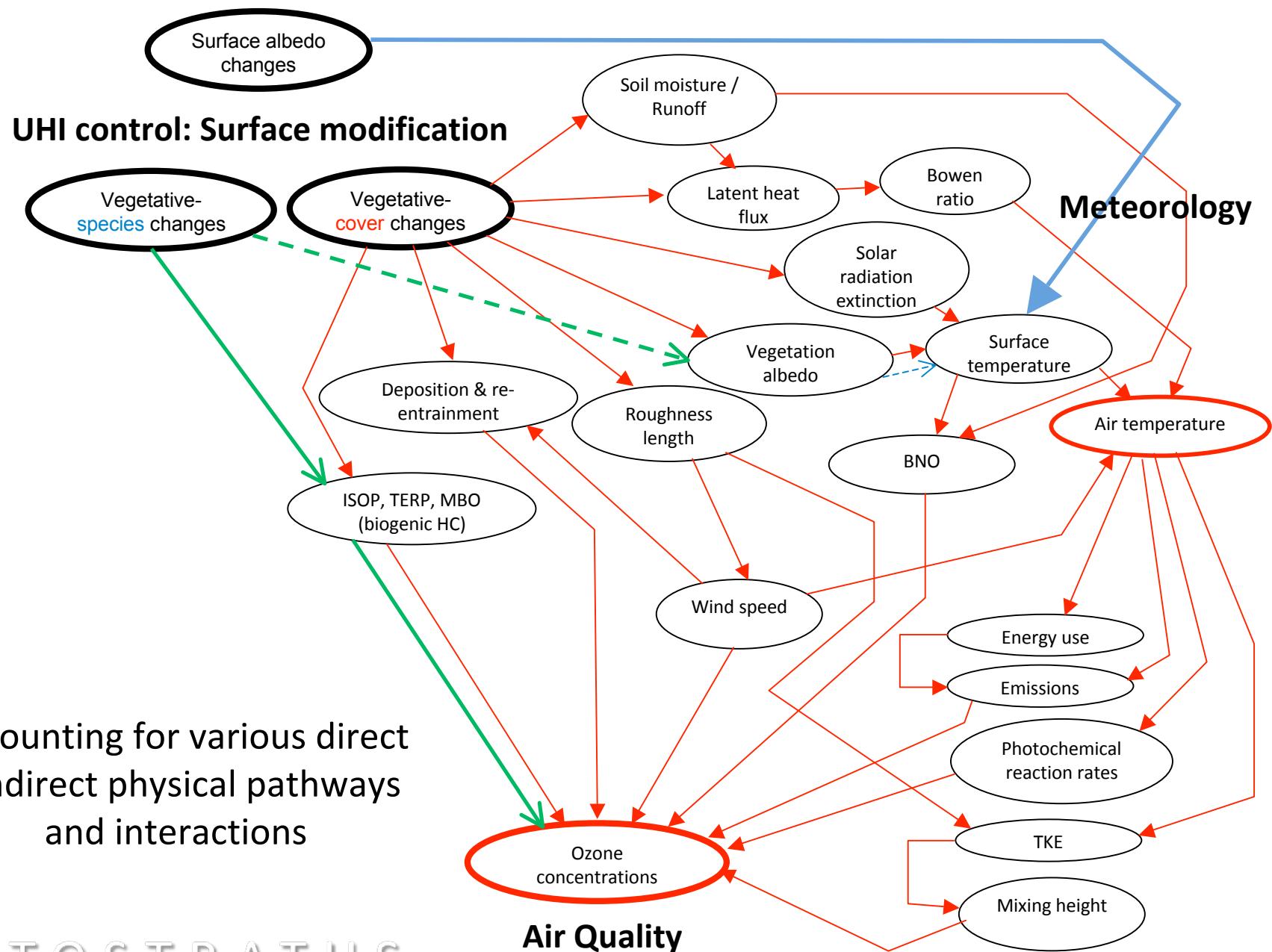
- Sacramento UFFCA project (SMAQMD):
 - SFNA VOC shortfall = **12 tpd** (from 2018 levels)
 - 6% of shortfall = **0.72 tpd** (if not shared)
 - Program to be achieved with **replacement** (low-emissions mix) and **net cover increase**
 - Modeling needed **to support or revise** findings to date in control measure





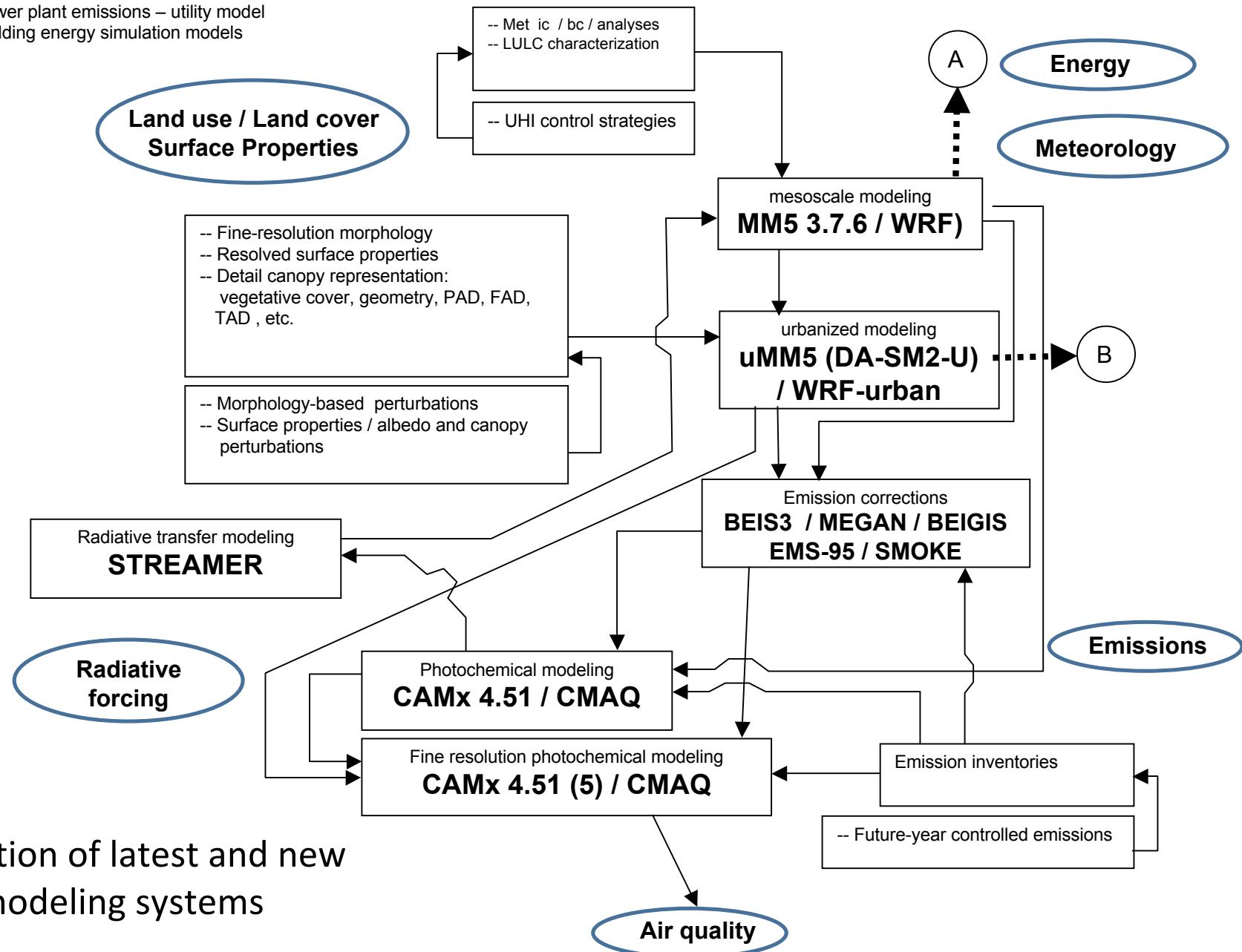
Thus **ongoing** models and data improvements:

- Surface characterization, urban morphology, land-use/land-cover – spatial / categorical resolutions
- Use of new parameters in models and tailor for UHI studies
- Meteorological model urbanization, photochemical model urbanization – fine resolution
- More resolved parameterizations – multi-directional (wind approach)
- Model performance to meet / exceed skill-demonstration benchmarks
- Conversion of AQ / CTM modeling results into emission equivalents
- Multi-episodic, seasonal, annual evaluations of impacts



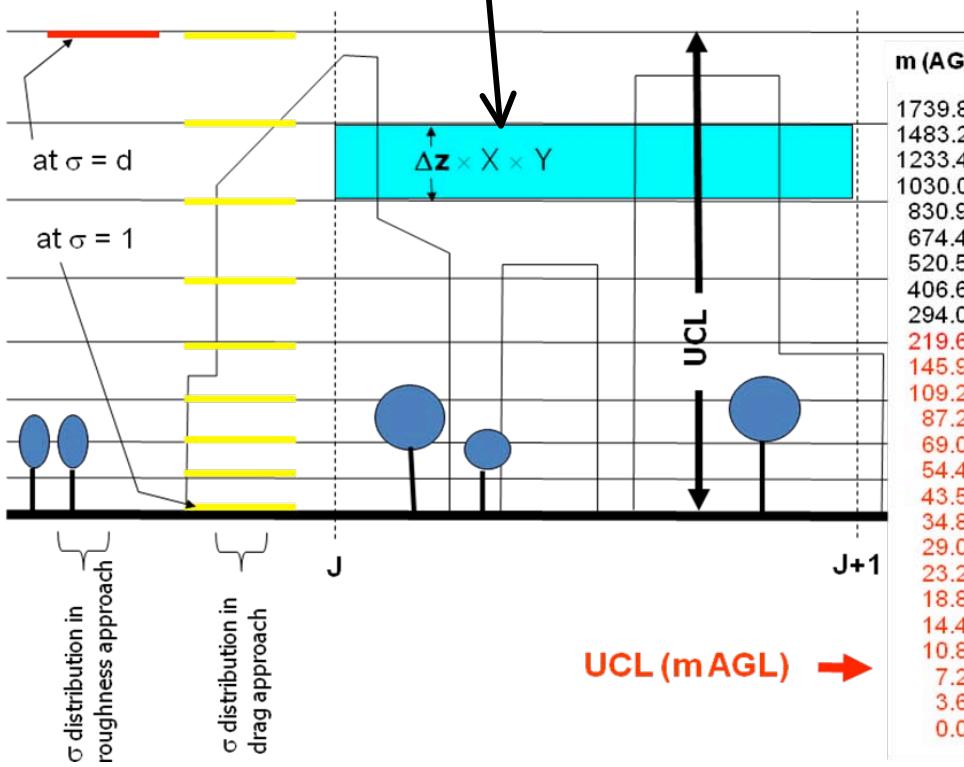
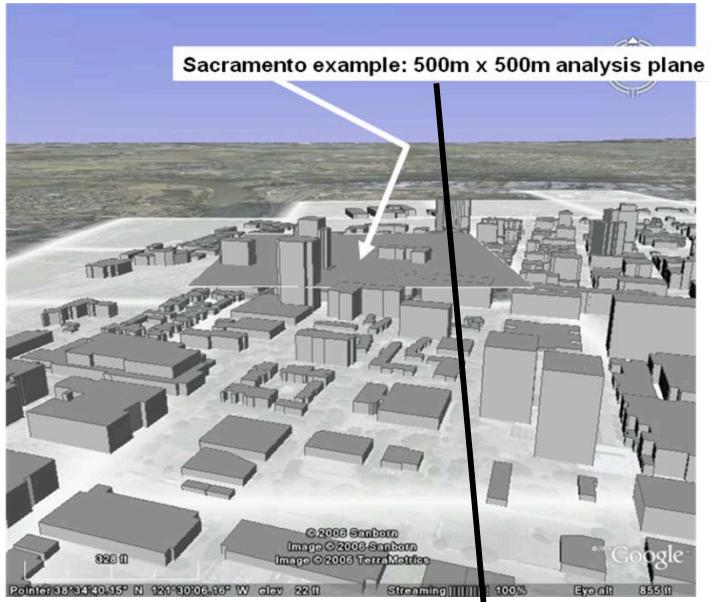
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A: Power plant emissions – utility model
B: Building energy simulation models



Utilization of latest and new modeling systems

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Introducing meso-urban
modeling capabilities, e.g.,
DA-SM2-U / uMM5

$$\frac{\partial \rho u_i}{\partial t} = F_{g(ui)} + \underbrace{F_{ui}^j}_{1} + \underbrace{\sum_j D_{ui}^j}_{2}$$

$$\frac{\partial \rho \theta_L}{\partial t} = F_{g(\theta L)} + \underbrace{H_j}_{3} + \underbrace{Q_f}_{4}$$

$$\frac{\partial \rho q}{\partial t} = F_{g(q)} + \underbrace{S_j}_{5}$$

$$\begin{aligned} \frac{\partial E}{\partial t} = & \frac{\partial u_i E}{\partial x_i} + \left\{ k_m \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right] S_{air} + F_E^{bui} \right\} + \left\{ \frac{g}{\theta_v} \langle w \theta_v \rangle + H_E \right\} \\ & - \frac{1}{\rho} \frac{\partial (\rho \langle w E \rangle)}{\partial z} - \varepsilon + \underbrace{\sum_j w_E^j}_{8} - \underbrace{\sum_j D_E^j}_{9} \end{aligned}$$

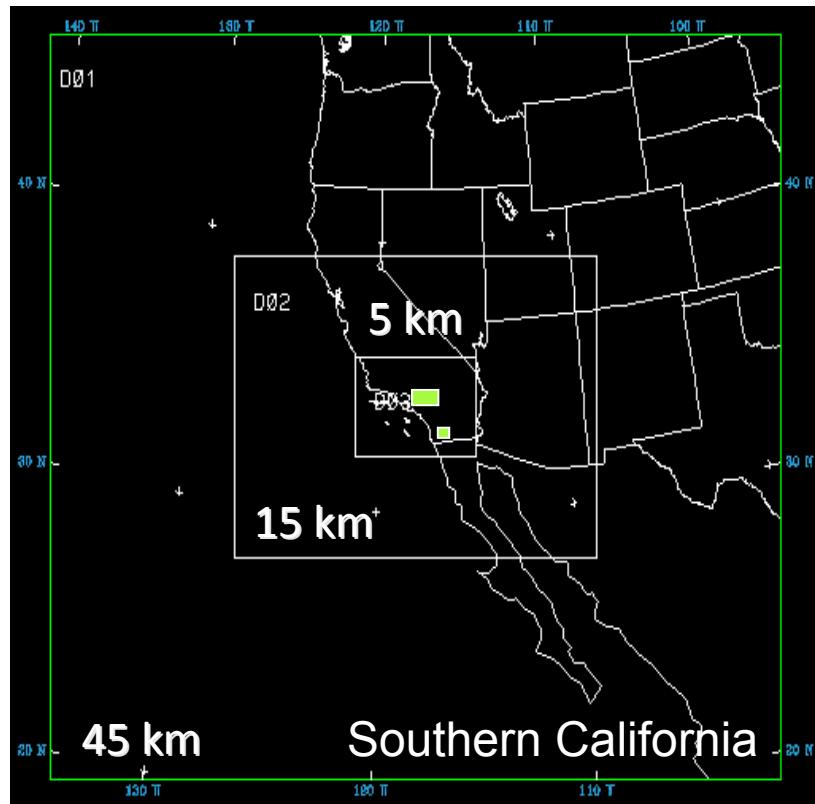
+ Urban geometry / effective
albedo / radiation trapping

+ Urban soil model (SM2-U)

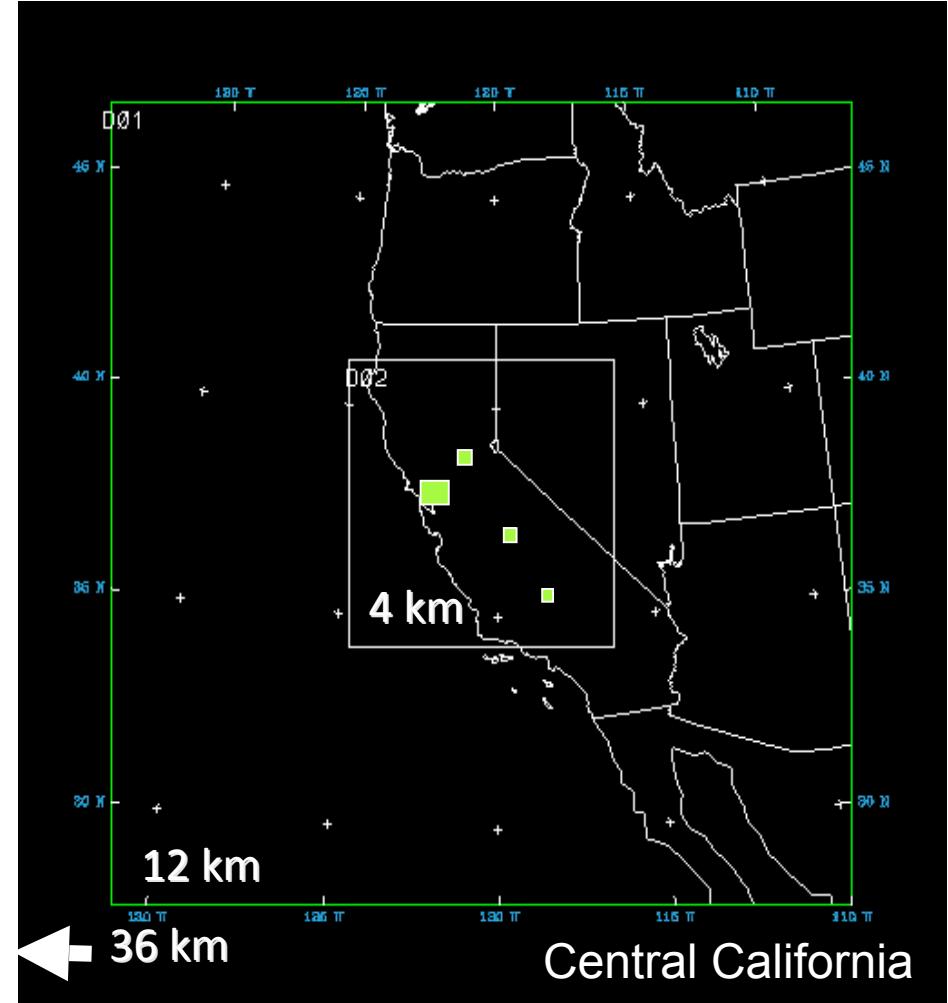
Source: Taha 2008b.
Boundary-Layer Meteorology

APPLICATIONS

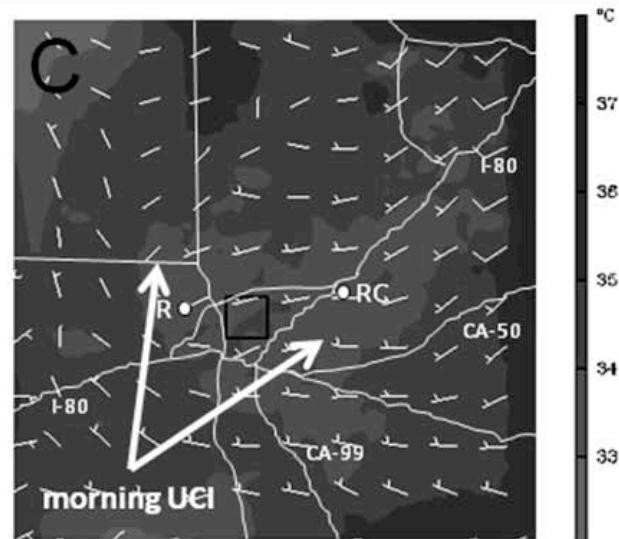
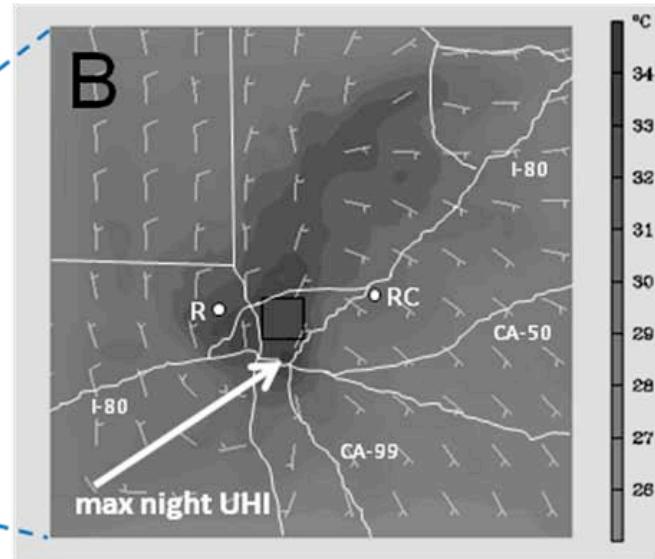
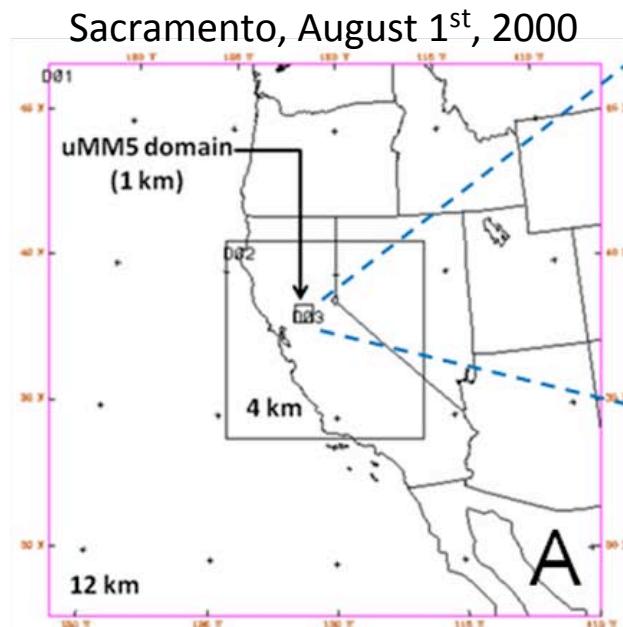
California example



- Mesoscale ($0 \sim 4\text{km+}$) modeling domains
- Meso-urban ($0 \sim 1\text{km}$) modeling domains



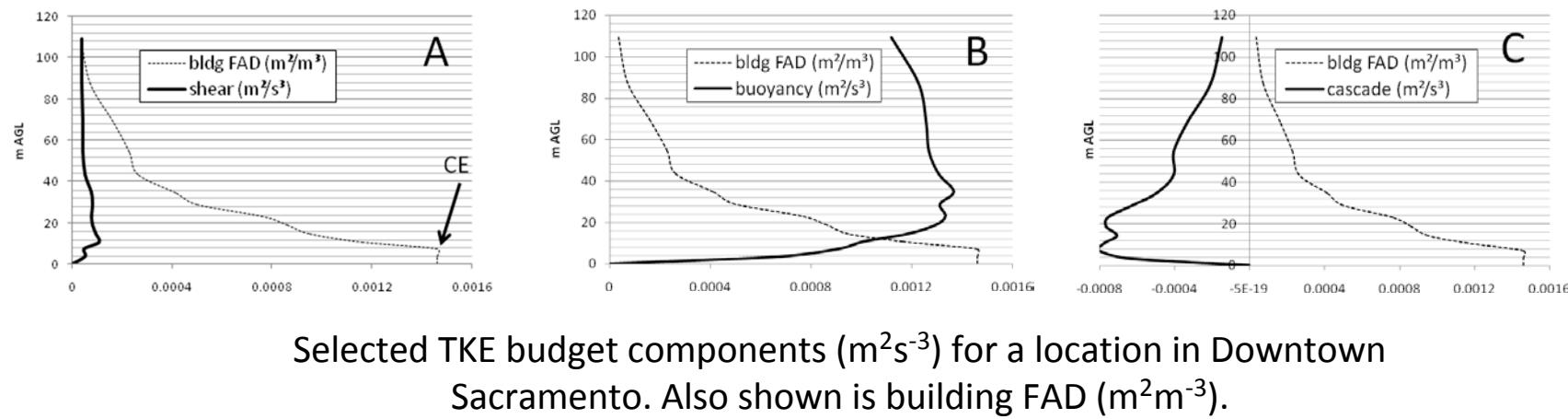
Meso-urban modeling base-case simulation results: heat island, cool island, flow convergence



Source: Taha 2008a.
Atmospheric Environment.

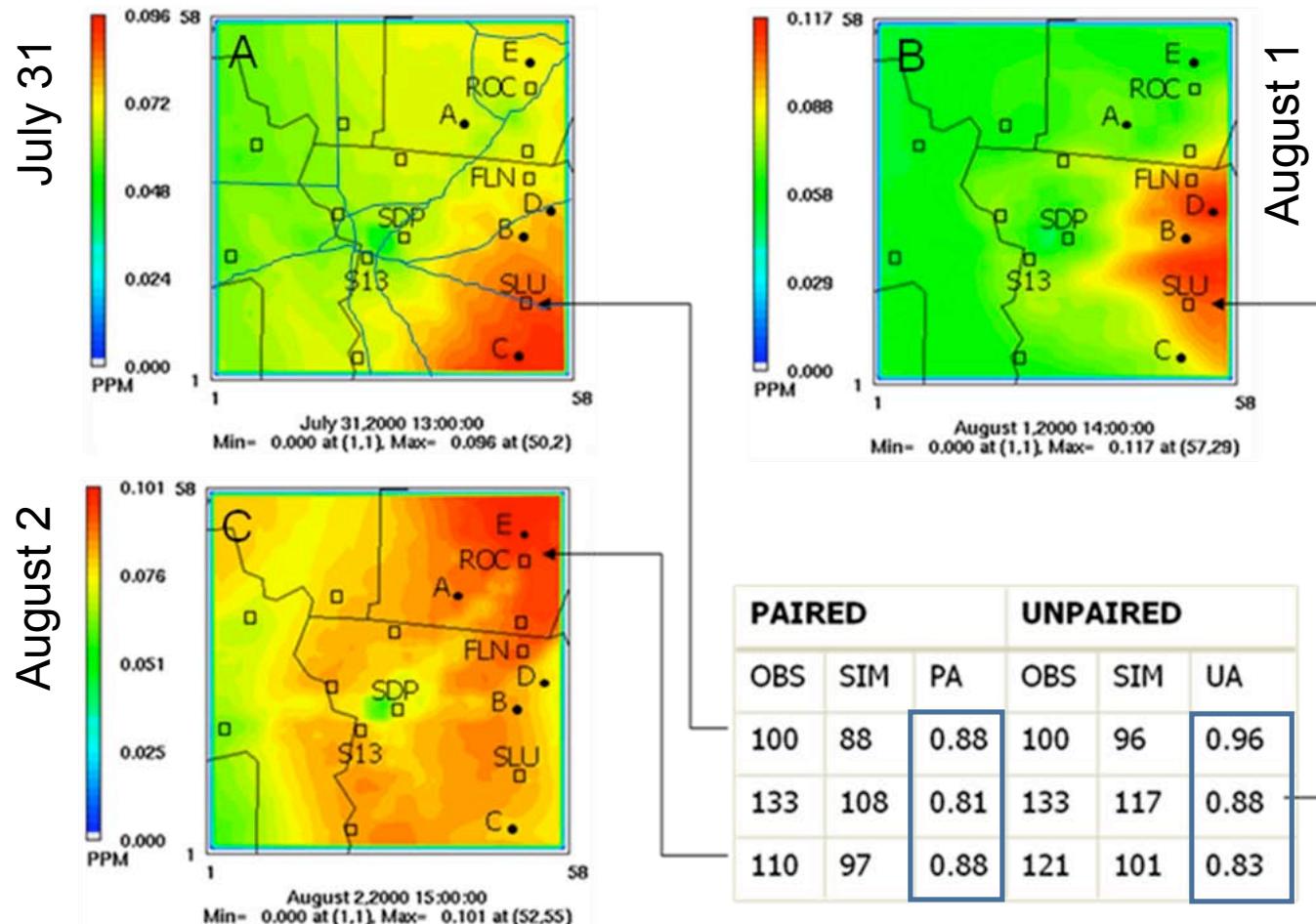
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Meso-urban modeling base-case simulation results: TKE budget components



Source: Taha 2008a.
Atmospheric Environment

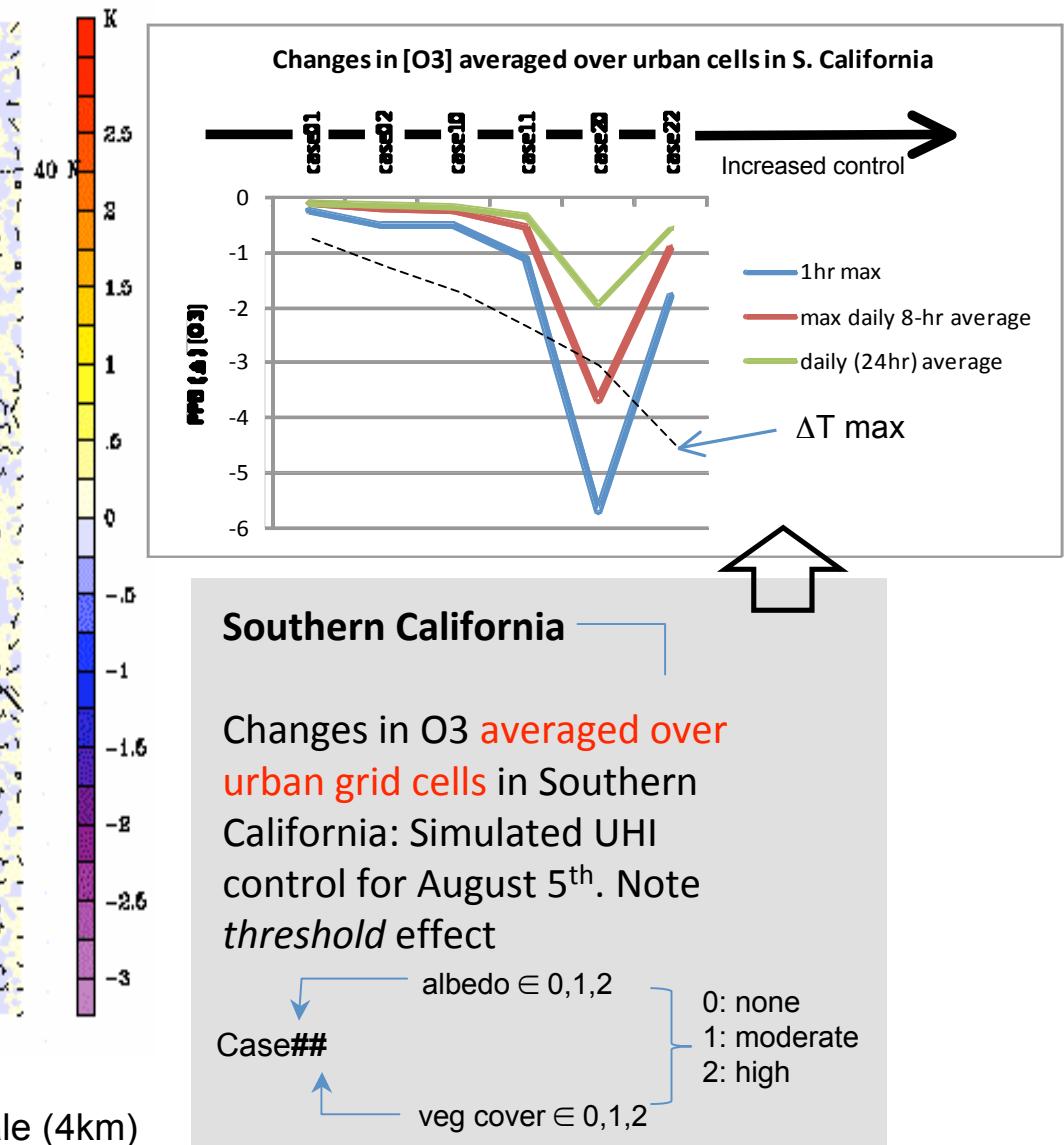
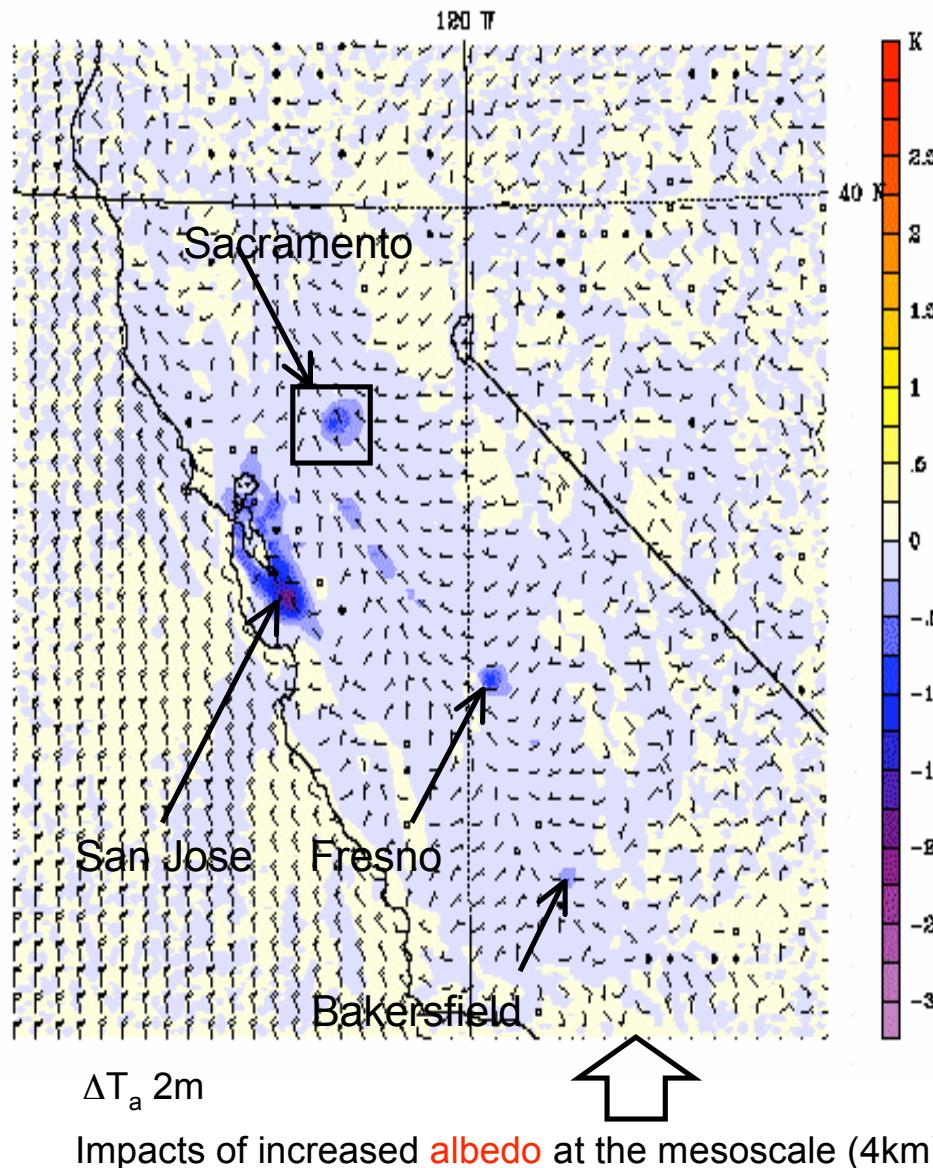
Meso-urban / fine-resolution photochemical modeling: Example (base) results for Central CA and Sacramento



Meso-urban meteorological and photochemical simulations : model performance

Source: Taha 2008c.
Atmospheric Environment

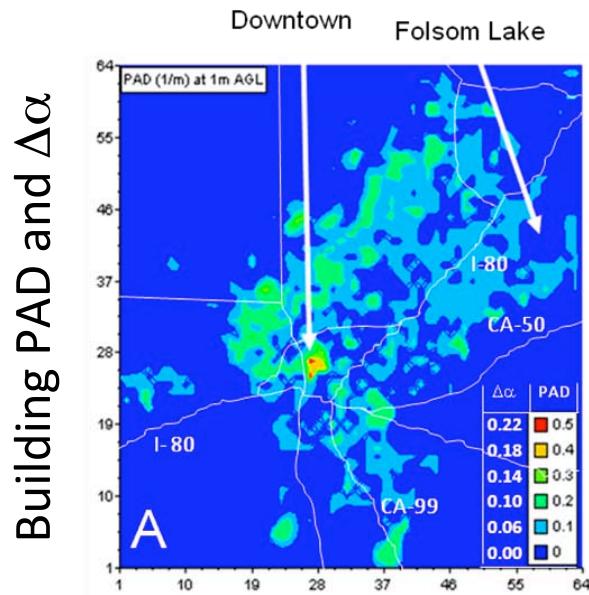
Evaluating impacts of UHI control



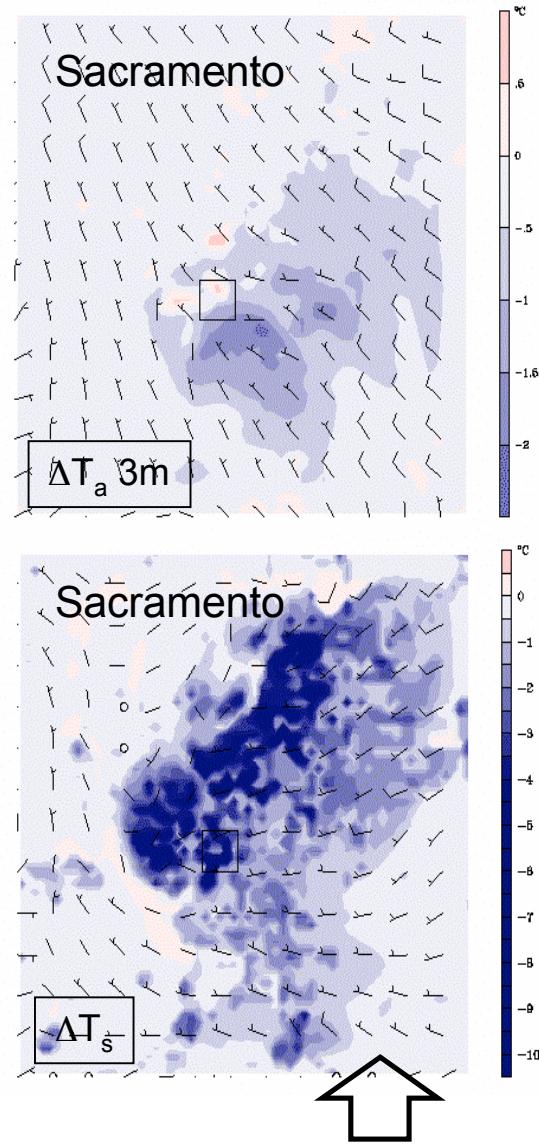
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Development of UHI control scenarios and evaluating impacts at the meso-urban scale, e.g., increased urban albedo

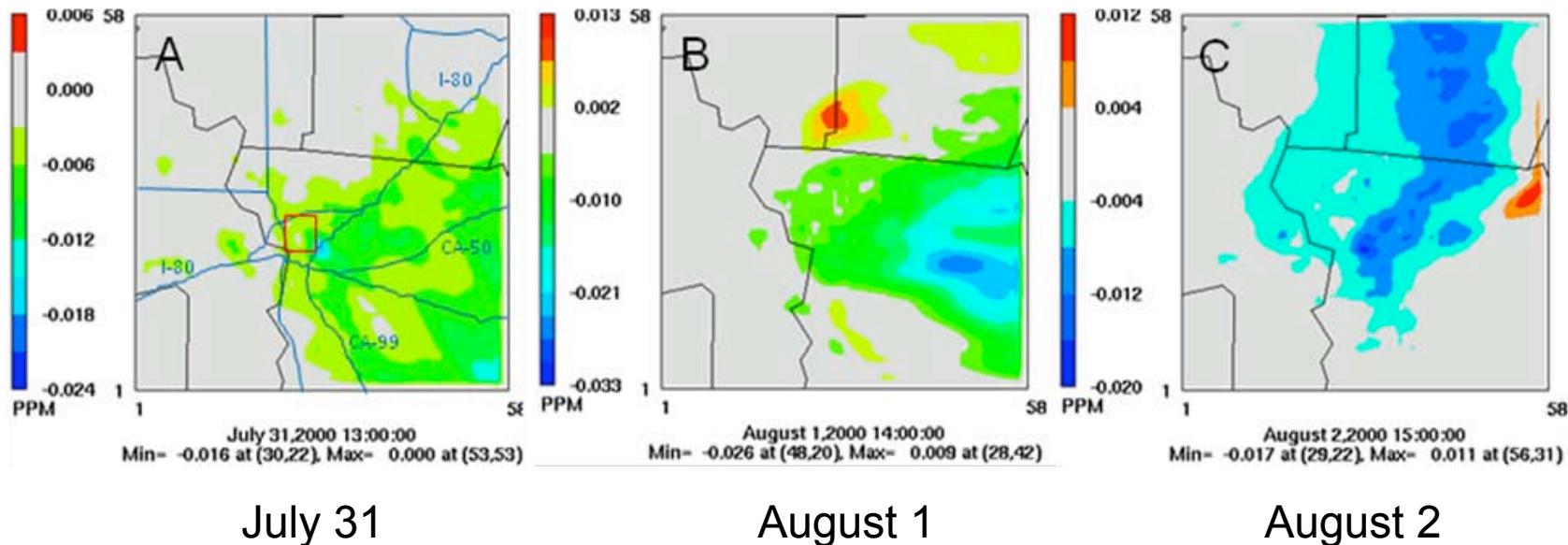
- Albedo (NOTE: $> 0.37 \mu\text{m}$)
- Vegetation (NOTE: BVOC emissions)
- Anthropogenic heat flux
- Storage heat flux / thermal mass
- Moisture and runoff
- Urban geometry



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Impacts of increased urban albedo on peak [O₃] : Sacramento example

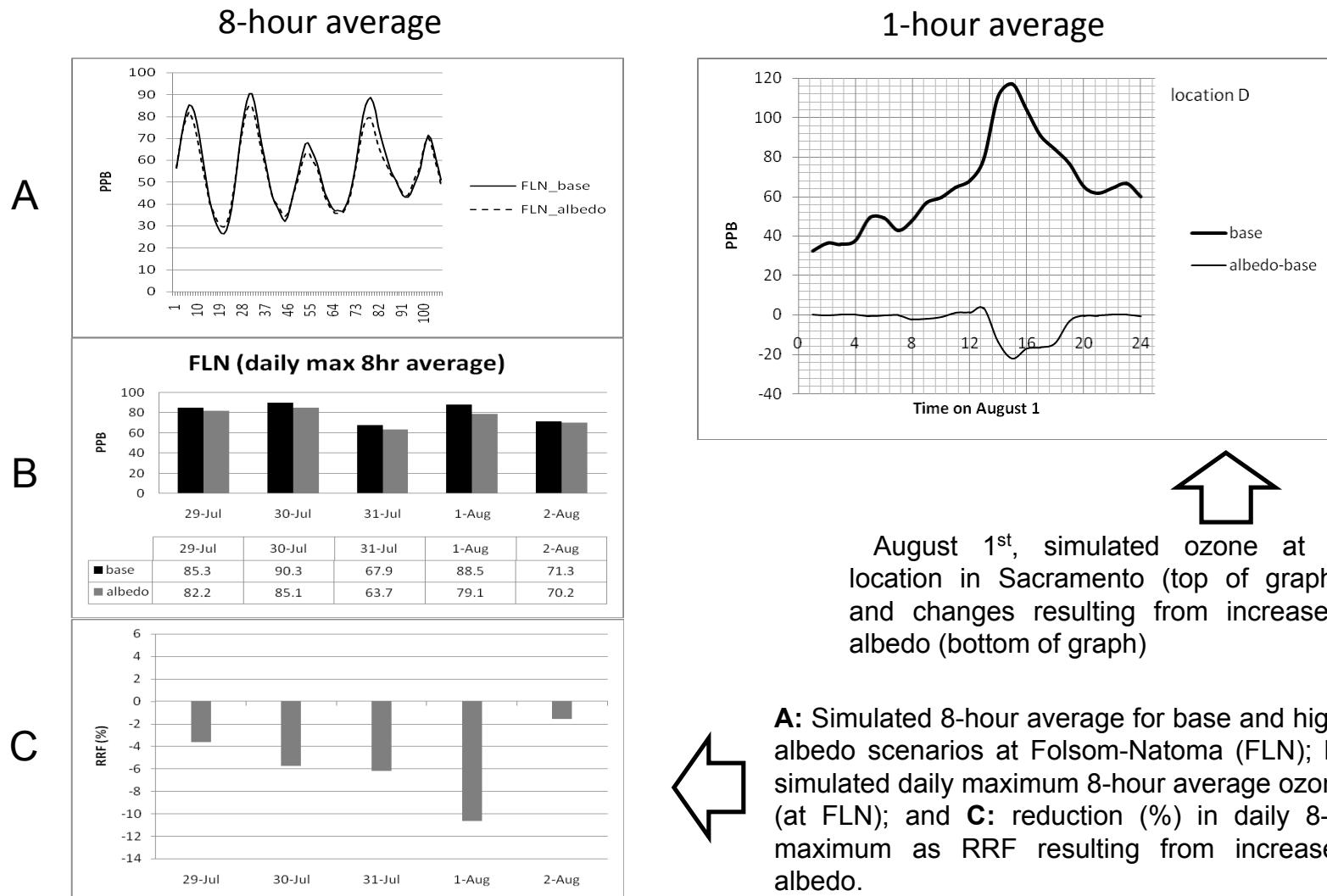


		Base-case peak (simulated)		Δ [O ₃] (ppb) at location of peak	
		Time of peak (LST)	Location of peak (see previous figure)	At time of peak	Max Δ [O ₃] at any time
	Peak (ppb)			Albedo - basecase	Albedo - basecase
July 29	103	1500	A	-8.7	-8.7 (at 1500)
July 30	113	1500	B	-10.9	-11.1 (at 1600)
July 31	96	1300	C	-8.1	-10.6 (at 1200)
August 1	117	1400	D	-22.2	-22.2 (at 1400)
August 2	101	1500	E	-6.7	-9.2 (at 1600)

Changes in [O₃] at time of base-case peak on each day of episode in the Sacramento **uMM5 domain** (resulting from increased urban albedo), corresponding to a decrease of up to 2-3 C in air temperature. Except for large localized decreases (or increases, e.g., on 1 August), average reductions affect large areas

Source: Taha 2008.
Atmospheric Environment

Potential air-quality improvements from increased urban albedo



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Source: Taha 2008.
Atmospheric Environment

Some implications for future (regulatory) modeling

- Each region / airshed must be modeled on its own due to specificities (e.g., threshold effects we showed earlier)
- Multi-episodic, seasonal, annual modeling needed to capture effectiveness of mitigation during a variety of ozone meteorologies (current CEC PIER project)
- Various climate subzones – thresholds affects again or local effects (current CEC PIER project)
- Conversion to emission reduction equivalents and emission credits

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THANK YOU!

REFERENCES CITED IN PRESENTATION

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